Chapter 2
Foredune Restoration in Urban Settings

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2.1 Introduction

Dunes will form anywhere there is a proper sediment source, a wind strong enough to entrain and move sediment, and a means of reducing the speed of winds or trapping the sand being moved. These conditions are readily met on most sand beaches, including those undergoing long-term erosion. The dunes may not survive erosion during major storms, but new dunes will re-form following recovery of the beach after storms. The reason sand dunes are not found landward of many active sand beaches in developed areas is because they are mechanically removed to enhance recreational use (Nordstrom 2008); in other cases, the beach is so severely truncated by human structures that the small unvegetated dunes that re-form are quickly eroded during the next storm. Once dunes are eliminated by human activities, they are lost from the consciousness of stakeholders, and attempts by managers to build new dunes are hampered by a lack of appreciation of their value (Nordstrom et al. 2000).

Sand dunes, like many other natural environments, provide important ecosystem functions and services (Lubke and Avis 1998; Arens et al. 2001; Peterson and Lipcius 2003; Everard et al. 2010), including:

1. Protection for human structures (providing sediment, a physical barrier or resistant vegetation)

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2. Sites for passive recreation (aesthetic, psychological, therapeutic opportunities)
3. Cultural/environmental heritage
4. Educational resource
5. Sand and minerals for extraction (consumptive use)
6. Filter for pollutants
7. Retention area for groundwater
8. Ecological niche for plants adapted to dynamic conditions
9. Habitable substrate for invertebrates
10. Refuge areas (e.g., for plovers, rabbits)
11. Nest or incubation sites
12. Food for primary consumers
13. Food for higher trophic levels (scavengers, predators, humans)
14. Synergistic benefits of multiple habitat types (e.g., corridors)
15. Intrinsic value.

The greatest value perceived by most managers is the protection dunes provide against flooding and erosion. Other values can be achieved through alternative designs for creating or modifying dunes, including providing niches for flora, habitable substrate and refuge areas for fauna, and nest sites. Dunes can also have site-specific value, such as sources of groundwater. In many locations, the resource base provided by the dunes has been lost through shorefront development, and human efforts are required to restore it.

The term "restoration" implies that attempts have been made to recover the form, function, and species inventory existing prior to human modification. Dunes built primarily to increase the level of protection from storm flooding and erosion are rarely restored because the landforms are built and maintained as static features in an attempt to protect against natural processes rather than respond to them. Nevertheless, most dune-building projects can accomplish some restoration goals if construction and management practices are made more compatible by accepting more natural features and greater mobility (Nordstrom et al. 2011).

Restoration efforts must be based on ecological, geomorphological and social criteria to maximize the goods and services dunes can provide. Steps in restoring dunes where they have been eliminated in developed areas involve:

1. Getting stakeholders to accept dunes as an alternative to the human-modified environments that have replaced them
2. Creating the basic landforms where they have been eliminated or increasing the size of truncated forms
3. Allowing these newly created or modified landforms to function like natural dunes by allowing some portions of them to be dynamic
4. Controlling subsequent negative human actions
5. Favoring dune evolution through time using adaptive management strategies.

Adaptive management, with continued human input, is critical where space is restricted and long-term erosion continues. Sustainability of natural features in developed areas requires that humans act as intrinsic agents of landform change.

Space and time are important to allow incipient dunes on the backshore to survive erosion by wave uprush during small storms and to increase in size to create foredune ridges large enough to survive storms of annual or greater frequency/magnitude. If space and time are not available, these constraints can be partially overcome by aiding natural processes using sand fences or vegetation planting, or by using earth-moving equipment. These human actions can be used to build and rebuild dunes in a sand-deficient environment, but inevitably, beach nourishment is required to maintain a healthy, well-vegetated dune on an eroding shore (Mendelssohn et al. 1991).

2.2 Dune-Building Practices in Urban Areas

We use the generic word "urban" to refer to both moderately and intensively developed shores (suburbs and cities). We do not distinguish between these types of shores because the largest lengths of developed dunes in some countries (e.g., the USA) occur outside cities. In many cases, it is not the intensity of development that is the issue, but the proximity of houses, protection structures and support infrastructure to the backshore, and the frequency of beach raking. The methods used to build dunes in developed areas are similar to those used in coastal parks and preserves. The differences affecting the way dunes look and evolve in developed areas are due to restricted beach widths or changes in grain size characteristics if beach fill is used. There is no fundamental difference in the ways dunes should be restored in developed areas except for the need to control some of the natural dynamism where human infrastructure is close to the water and to control subsequent degradational human activities.

2.2.1 Accommodating Natural Aeolian Processes

The biological and geomorphological processes forming new or incipient natural foredunes on undeveloped beaches are reviewed in Hesp (1989, 1991) and Kuriyama et al. (2005). On these beaches, wind-blown sand will accumulate at the seaward-most vegetation and wrack lines that form on the backshore. These dune-forming features are missing on raked beaches. On many human-altered shores that are eroding, the presence of infrastructure close to the water restricts backshore width, requiring artificial nourishment to provide the wider sediment source for aeolian transport and greater protection for newly formed dunes from wave erosion. As a result of growth by slow natural accretion, the resulting dune will have the internal stratification, topographic variability, surface cover, and root mass of a natural dune. The wide cross-shore gradient of physical processes will allow for a suite of distinctive habitats, from pioneer species on the seaward side to woody shrubs and trees on the landward side. A large-scale beach nourishment

Fig. 2.1 Evolving dune on a nourished beach at Ocean City, NJ, USA (2009), 16 years after dune-building began. The ridge to the far left, fronting the houses, is the initial protective dune that now functions as a species-rich secondary dune. The foredune in the foreground was created by natural processes without the aid of fences or vegetation planting

project can provide the necessary sand volume and space for dunes to form (Fig. 2.1), but time is required for backdune species to colonize, and maintenance nourishment of the beach is required to retain dune integrity, given subsequent wave-induced erosion.

The characteristics of beach fill and the design elevation of the berm crest influence the likelihood of aeolian transport and delivery of sand to the dune. The removal of finer sands from poorly sorted fill sediment can leave a coarser shell or gravel lag surface that resists subsequent aeolian transport (Psuty and Moreira 1992; van der Wal 1998). Storm reworking of the backshore can replenish the finer sand and initiate new cycles of increased aeolian transport, but the elevation of the nourished beach must be low enough to allow storm wave run-up to occur on the backshore. The common practice of building a beach higher than a natural beach to provide protection to human infrastructure against run-up should be avoided if natural aeolian transfers are to be favored (Jackson et al. 2010).

Under natural conditions, restoration of the morphology and vegetation assemblages of foredunes can take up to 10 years (Woodhouse et al. 1977; Maun 2004). Accordingly, it may be desirable to use earth-moving equipment, sand fences or vegetation planting to create a dune ridge for initial protection and allow a more natural dune to gradually evolve toward the sea. Creation of this initial barrier will eliminate the need for an overly nourished beach to provide flood protection. Construction of the original protective foredune in the left background of Fig. 2.1 was facilitated by initial placement of two sand fences and plantings of *Ammophila breviligulata*. Additional fences were placed on the seaward side of the dune to encourage horizontal rather than vertical growth, so that shore-front residents could retain views of the sea. Designation of nesting sites for piping plovers by the state endangered species program resulted in the prohibition of beach raking, leading to local colonization of the backshore by plants and growth of incipient dunes that survived several winter storm seasons and grew into the new foredune ridge farther seaward (foreground of Fig. 2.1).

Fig. 2.2 Dune at Carolina Beach, NC, USA (1981), created using artificial fill reshaped by bulldozers into a dune-dike

2.2.2 Direct Deposit of Fill

Dunes are frequently constructed by directly depositing sediment and reshaping it using earth-moving equipment. These landforms, often called dune-dikes, are usually built to optimize a flood-protection function and often have a flat top or planar sides of a consistent slope with little topographic diversity (Fig. 2.2). Dune-dikes may retain their artificial form through time if no subsequent aeolian accretion occurs or if they are rebuilt to the same template when they erode. They may eventually evolve to resemble more hummocky natural dunes with greater variability of microhabitats if they are not repeatedly rebuilt or revegetated.

The grain size characteristics, rates of change, and characteristic vegetation of dunes built by mechanical placement differ from dunes created by aeolian deposition (Baye 1990; van der Wal 1998; Matias et al. 2005). Bulldozed dunes may include coarser shells and gravel, but they can have well-sorted sands that resemble dune sediments if suitable borrow areas are used to build them. Bulldozed dunes can provide habitat similar to natural dunes, if actions are taken to enhance this value during and after construction. Patchiness of habitats can be increased by creating an undulating foredune crest, resulting in local differences in drainage and wind speed and converting the landward boundary from a line into a zone (Nordstrom 2008). Subsequent deposition of wind-blown sand on a bulldozed dune can create surface characteristics similar to a natural dune if no barriers to aeolian transport are created seaward of it. This deposition can be accelerated by using beach fill materials compatible with aeolian transport, employing sand-trapping fences on (but not in front of) the nourished dune, and creating a gentle seaward slope in the initial fill deposit (Matias et al. 2004, 2005).

2.2.3 Using Sand Fences

Fencing materials include canes and tree branches inserted directly into the sand and wooden slats, plastic, and jute fabric attached to fence posts. Using sand fences with different characteristics and configurations can result in considerable variety in foredune topography and vegetation. Straight fences placed parallel to the shore appear to provide the most economical method of building protective dunes (CERC 1984; Miller et al. 2001). Zig-zag fences can create wider dunes with more undulating crest lines and more gently sloping dune faces that are closer to the shapes of natural dunes (Snyder and Pinet 1981). Paired fences can create a broader based foredune with a rounded crest that can look more natural (Schwendiman 1977). Side spurs perpendicular to straight alongshore alignments can increase trapping rates in locations of strong longshore winds. Multiple lifts of fences can create a higher dune with much greater volume than single lifts (CERC 1984; Mendelssohn et al. 1991; Miller et al. 2001).

Sand accumulation efficiency and morphological changes depend on fence porosity, height, inclination, the scale and shape of openings, wind speed and direction, the number of fence rows, separation distance between fence rows, and placement relative to the existing topography. Fencing with a porosity of about 50 %, with space between open and closed areas of less than 50 mm, can fill to capacity in about a year where appreciable sand is moving, but vegetation planting may still be required to stabilize the surface (CERC 1984) and establish a more natural trajectory.

A fence placed at the seaward limit of natural vegetation or at an existing foredune line may be far enough landward to survive a wave attack during small storms and have a wide source of wind-blown sand seaward (CERC 1984). Where diagnostic vegetation is lacking, dunes built with fences appear likely to survive storms at least a 1 year apart if they are built landward of the upper-most storm wrack line. The decision about where to place fences on a beach widened by fill or storm wave overwash could be made taking into account whether it is desirable to create a dune with space devoted to low wet habitats (slacks) between landward and seaward ridges or a higher, drier, and more continuous dune with multiple ridges (Nordstrom 2008). In these cases of a widened beach, the landward fence could be at least 100 m from the active beach, as suggested by Dahl and Woodard (1977) and Miller et al. (2001).

Sand fences or vegetation plantings are often used to stabilize newly-formed bare areas, forming gaps in the existing dunes. Depending on how, when or whether gaps are sealed, a foredune could reflect the differences in topography and cyclic reversals in vegetation succession found on a more dynamic natural landform or the more uniform sequences found on a stable landform. Constructing new fences is a more traditional and conservative approach, but one that should be evaluated more carefully considering the lower restoration potential of the resulting linear dune.

2.2.4 Using Vegetation

Vegetation reduces wind speed, traps sand, stabilizes surface sediment, provides habitat, and improves aesthetic appeal (Schwendiman 1977; Hesp 1989; Mitteager et al. 2006; Nordstrom 2008). The characteristics of the vegetation have important implications for the goods and services provided by coastal dunes. Basic dune-stabilizing vegetation for use by municipal managers and residents should consist of native species that are easy to propagate, harvest, store, and transplant with a high survival rate, be commercially available at local nurseries at a relatively low cost, and be able to grow in a variety of microhabitats on a spatially restricted foredune (Feagin 2005; Mitteager et al. 2006). The species that are most useful in building foredunes rapidly react positively to sand burial (Maun 1998). When sand deposition diminishes, initial dune-building species can degenerate, but successional species can be planted where sand deposition cannot be reinitiated (van der Putten and Peters 1995). Degeneration of *Ammophila* (*arenaria* or *breviligulata*, whichever is native), for example, is not a problem where the loss is coincident with colonization by later successional species (Vestergaard and Hansen 1992).

Other species may be more suitable for planting in environments landward of the active foredune crest, e.g., *Spartina patens* in dune swales, but the use of other species may not be necessary because they will eventually opportunistically colonize the dune themselves (Feagin 2005). Stabilizing the sand surface with one species can ameliorate environmental extremes and facilitate the establishment of other species that are less adapted to stressful environments (Martínez and Garcia-Franco 2004; De Lillis et al. 2004). Endangered species can colonize restored areas if populations and seed sources are present nearby and if dispersal mechanisms (wind, water or animals) are effective (Avis 1995; Snyder and Boss 2002; Grootjans 2004), although sometimes endangered species need some assistance to colonize.

2.3 Retaining an Element of Natural Dynamism

Natural foredunes are inherently dynamic and fragmented, with portions in an incipient state and portions at a more developed stage (Ritchie and Penland 1990; Doody 2001). Some degree of natural dynamism is important to allow landforms to be diverse and self-sustaining (Nordstrom 2008). Tolerance to burial is an important cause of zonation of plant species on coastal foredunes, and burial can have a stimulating, positive effect on the growth of dune-building plants and prevent degeneration (Maun 2004). Many plant species can occur in sand dunes, but the species most dependent on dune habitat tend to be concentrated in zones with greater sand movement (Castillo and Moreno-Casasola 1996; Rhind and Jones 1999). The variety of local topographic relief and small-scale differences in sheltering and proximity to the water table enhance the variety of habitats across and along the shore, and the resulting ecosystem services they provide (Everard et al. 2010).

The limit to how much dynamism can be tolerated by shorefront stakeholders is often related to the distance between the dune crest and the nearest human infrastructure. Foredunes can be allowed to erode or be breached by storm waves if the infrastructure is not close to the foredune and the foredune is not the only protection (Arens et al. 2001; Nordstrom et al. 2007), but dunes in most developed areas are narrow and close to human facilities and may not be allowed to evolve solely by natural processes. Ongoing human efforts may be required to allow portions of the dune to be mobile and evolve through time, while the overall feature remains intact as a barrier against storm wave run-up. These efforts will involve controls on beach raking, the use of sand fences and human-use structures on the beach and in the dune, driving on the beach, managing endangered species, and using exotic vegetation as ground cover. Establishing criteria for managing dunes in developed areas as partially dynamic systems is a difficult task. Many of the methods used to create dunes where they do not exist or to increase the dynamism of stabilized dunes represent departures from past practices, so it is likely that most projects will be experimental and small-scale and require a strong public information component until the feasibility of large-scale future projects is demonstrated.

2.4 Controlling Negative Human Actions

2.4.1 Restricting Beach Raking

Wrack (natural litter) lines contain seeds, culms, rhizomes of coastal vegetation, wood debris, and nutrients that aid in the growth of new vegetation and sand accumulations that evolve into new dunes (Godfrey 1977; Ranwell and Boar 1986) The highest storm wrack line has the greatest amount of litter and is often far enough landward of wave uprush during small storms to survive long enough to provide the base for a new foredune. Raking to remove wrack eliminates the likelihood of natural cycles of growth and destruction of incipient dunes on the beach, and eliminates backshore habitats and the associated biodiversity. Raking is one of the most common environmentally damaging actions on shores developed for human use (McLachlan 1985; Nordstrom et al. 2000; Colombini and Chelazzi 2003; Dugan et al. 2003). Finding a way to retain wrack is critical to conserving or restoring beach and dune habitats in developed areas. Alternatives for wrack management include:

1. Selectively removing the cultural litter and leaving the natural litter using nonmechanical methods
2. Leaving the highest storm wrack line on the backshore while raking the beach below it
3. Restricting cleaning operations to the summer (tourist season) or after massive fish kills

4. Leaving longshore segments unraked to develop as natural enclaves (Nordstrom et al. 2000).

2.4.2 Restricting Use of Sand Fences and Other Structures

There is often greater use of sand-trapping fences than is necessary (Grafals-Soto and Nordstrom 2009). Sand fences should not be placed where a dune of adequate size already exists, where they would trap sand in unnatural configurations, or where they cannot be buried, such as in vegetated portions of the dune or too close to the water. Fences in these locations can be conspicuous intrusions in the landscape, acting as physical boundaries to movement of fauna and reminders of the artifactual nature of the dunes. In many cases, sand-trapping fences need only be used for creation of the first dune ridge that functions as the core around which the natural dune can evolve (Nordstrom et al. 2000; Grafals-Soto and Nordstrom 2009). The location of the contact between the foredune and backshore is determined by erosion of the foredune during storms and dune accretion following storms. Storm wave uprush may eliminate the seaward portion of the dune and create an erosional scarp, but post-storm beach accretion creates a new source of sand to be blown to the foredune, reestablishing the dune sediment budget.

Biodegradable fences can be used to create an initial dune ridge while avoiding the long-term hazard to fauna and diminishing the human footprint in the landscape (Miller et al. 2001). Interference with movement of fauna can also be reduced by employing fences in configurations that create cross-shore corridors, either by leaving short gaps in longer sections of fence or deploying fences as short sections oriented transverse to shore and to prevailing winds. Sand-trapping fences are often used to control visitor traffic, resulting in dunes with unnatural shapes. Symbolic fences may be used instead of sand-trapping fences for controlling pedestrian access. Symbolic fences prevent users from trampling the dune while allowing the sand blown landward to build up dune height and volume.

Reducing the physical and visual impact of all structures can create a more naturally appearing and functioning beach and dune environment. Removable or elevated structures are often authorized on the beach and dune because of the reduced threat to their damage, but these structures enhance the feeling that coastal landforms are recreational areas. Actions to enhance recreational areas, such as grading surfaces and building walkways for access, can increase the level of physical and visual disturbance. Shore-perpendicular access paths are required to allow beach use, but they do not have to be as numerous as they are in most locations.

2.4.3 Restricting Driving on Beaches and Dunes

Vehicles driven on beaches kill fauna and disperse organic matter in drift lines, thereby destroying young dune vegetation and losing nutrients (Godfrey and Godfrey 1981; Moss and McPhee 2006; Foster-Smith et al. 2007). Vehicles compact the sand, which then becomes a hard surface and less viable for seed germination or for animal burrowing. The unnatural landscape image created by vehicle tracks can undermine attempts to instill an appreciation of the shore as a natural environment. Thus, driving should be restricted to only a few segments along a beach or to portions of the beach between wrack lines and away from incipient dunes; shore-perpendicular access could be restricted to a few prescribed crossings (Nordstrom 2003; Priskin 2003). There is little reason to allow private vehicles on beaches in developed municipalities when road networks exist landward and where undeveloped enclaves are so small that beaches can be reached on foot. Even if private vehicle use is prevented, municipal vehicles used for patrolling the beach and for emptying trash receptacles may remain a problem. Instituting a haul-in/haul-out policy for garbage generated by tourists would reduce the need for trash receptacles on the beach. Vehicles used for public safety could be confined to emergency operations.

2.4.4 Re-evaluating Endangered Species Programs

Initiatives for protecting endangered fauna, such as birds and turtles, by controlling active human uses has resulted in the creation and protection of naturally functioning beaches and dunes (Nordstrom et al. 2000; Breton et al. 2000). Identification of nests on beaches can lead to suspension of raking, bulldozing, and driving on the beach during the nesting season, leading to accumulation of litter in wrack lines, colonization by plants, and growth of incipient dunes that may evolve into established foredunes (Fig. 2.1). Protection of endangered species can have negative effects when the landscape is modified specifically for them and the needs of other species are subservient to the endangered ones. Programs to enhance conditions for nesting shorebirds can lead to artificial flattening of topography and the clearing of vegetation, and can prevent the backshores and dunes from evolving to later stages. Ways must be found to make these environments function naturally and compatible with other species dependent on a coastal setting.

2.4.5 Controlling Exotic Species

Exotic vegetation was often planted in dunes in the past because it was seen to be effective in stabilizing dunes, valuable economically, or attractive. Many public agencies now recognize the adverse effects of exotics on the biodiversity, authenticity, and successional processes, and have attempted to eliminate problematic species. The problem with the invasion of exotics from nearby residential and commercial properties is a less publicized issue. The magnitude of the problem is exacerbated if the foredune occurs on private property and if regulations allow property owners to plant exotic vegetation. Landscaping choices of individual shorefront property owners and managers of hotels and condominiums are conditioned by past experiences that are often obtained in a noncoastal setting, causing them to think that exotics are the landscaping ideal. Achieving restoration goals on private lots is an important, but virtually ignored, field of inquiry that has enormous potential for improving the natural value of coastal resources (Mitteager et al. 2006).

2.5 Gaining Acceptance for Natural Landforms and Habitats

Convincing residents and municipal officials of the need to create dunes where they do not exist or allow stable dunes to function more naturally can be challenging (Nordstrom 2008). The first step in building new dunes may be to build any dune-like feature, even if low, narrow, linear, and fixed in position, as has occurred in the State of New Jersey (Mauriello and Halsey 1987; Mauriello 1989). Gaining acceptance of larger, more naturally functioning dunes requires demonstrating their value by providing examples of good management practice and implementing public education programs, e.g., the municipal program in Avalon, NJ, USA (Nordstrom et al. 2009). Local demonstration sites can be used to provide specific technical information to local managers and provide evidence that restoration options are achievable (Breton et al. 2000; Nordstrom 2003). Demonstration sites in developed municipalities should have similar space constraints and relationships to the natural and cultural features of future restoration sites. Purely natural environments would likely represent unachievable target states. Policies should include restrictions on the mechanical removal of litter, the use of vehicles on the beach, and the use of sand-trapping fences. Portions of dunes should be dynamic once they have achieved dimensions required for shore protection. Only native vegetation should be used in planting programs, and any exotic species should be removed.

Instituting change in environmental practice is difficult without a strong education component. Education efforts must be conducted via multiple means to reach different user groups, and they must be ongoing because the turnover in population can be rapid. Actions at the municipal level include newsletters, instruction in public schools, tours of demonstration sites, displays in libraries, presentations at town meetings, mailings of flood hazard information to property owners, and information signs at key field locations (Breton et al. 2000; Nordstrom et al. 2009). It is important to specify the role of human actions in both the degradation and the restoration of natural environments.

2.6 Maintaining and Evaluating Restored Environments

Monitoring and adaptive management are important in assessing:

1. Whether restoration goals have been achieved
2. What kind of follow-up actions are required
3. How plans can be modified to achieve better future projects.

Evaluations should be conducted several years after dune building begins, so that managers can appreciate the time required for a resilient species-appropriate vegetation cover to become established and have realistic expectations of restoration outcomes. Understanding the multifaceted aspects of dune change is critical. Evidence of sand movement within the dunes may be considered beneficial in terms of habitat rejuvenation and biodiversity, but problematic in terms of the potential for the inundation of human infrastructure or the loss of an existing valued species dependent on a stable surface. Thus, changes to the form and function of the restored dunes should be expected and evaluated according to multiple criteria.

2.7 Conclusions

Attempts to restore dunes in developed areas must overcome restrictions in space and time as well as negative attitudes about their value. Restrictions in space and time can be partially offset by aiding natural processes through bulldozing, fencing, and planting programs, but dunes will provide more of their potential functions and services if they are allowed to evolve naturally and not managed as static landforms solely for shore protection. Restrictions to degradational practices, such as raking or driving on beaches, using sand fences well after the dune has formed, and allowing a single species to dominate management efforts will help dunes recover and provide a broader range of values, but recovery from the results of past practices will require more attention to education and adaptive management programs.

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